CeLAND:
PBq ^{144}Ce-^{144}Pr source in KamLAND

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KamLAND collaboration
University of Hawaii
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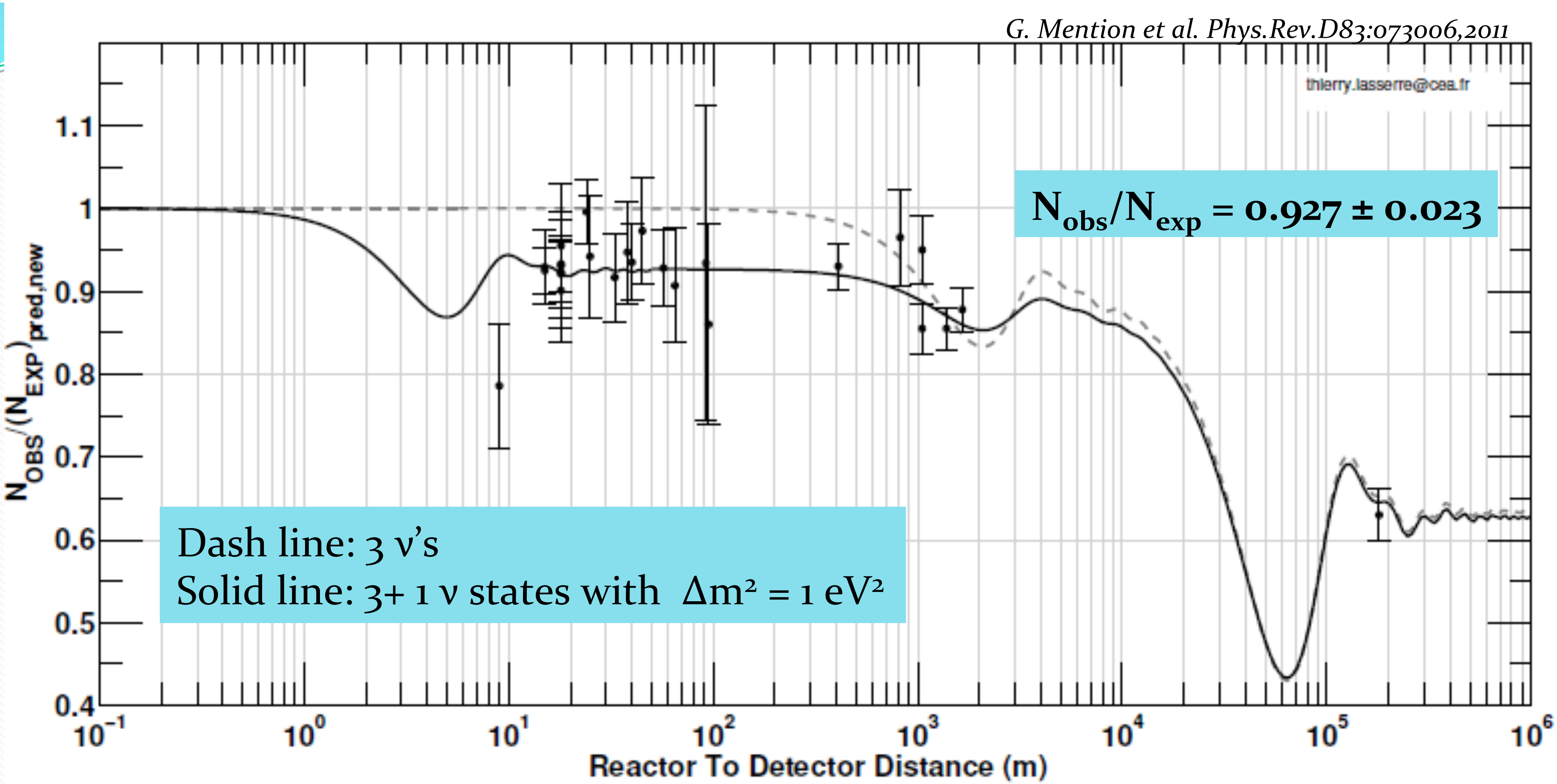
Outline

- Physics motivation for the very short baseline neutrino oscillations search
- Concept of the antineutrino generator experiment
- ^{144}Ce-^{144}Pr PBq antineutrino generator
- Search for sterile neutrinos in KamLAND with ^{144}Ce-^{144}Pr PBq source: CeLAND
- Shielding, transportation, deployment
- Sensitivity to short baseline oscillations
- Summary and future steps

Motivation for the short baseline antineutrino search

G. Mention et al. Phys.Rev.D83:073006,2011



- Reactor Antineutrino Anomaly → existence of 4th neutrino $\Delta m^2_{new} \sim 1\ eV^2$?
- Independent indications from accelerator experiments LSND and MiniBooNE
- Galium anomalies – 2.7 σ detected neutrino deficit observed in deployment of ^{51}Cr and ^{37}Ar sources in GALEX and SAGE solar neutrino experiments

→ *Motivates search for new neutrino $\Delta m^2_{new} \sim 1\ eV^2$ with very short oscillation baseline ~ 1m in 1-10 MeV range, which has never been tested before*

Testing short baseline oscillation

- If the 4^{th} neutrino is present and oscillates → distance-dependent flux from the source will demonstrate it at the distances of the order of oscillation length from the neutrino source

$$L_{osc}[m] = 2.48 \frac{E_{\bar{\nu}_e}[MeV]}{\Delta m^2_{new}[eV^2]}$$

- In case of sterile neutrino $\Delta m^2 \sim 1\text{-}2\ eV^2$, oscillation distance of interest is of the order of couple of meters.

- Large liquid scintillator detectors such as KamLAND, Borexino and SNO+ are sufficiently large to observe distance dependent oscillations signature from electron neutrino/antineutrino to proposed 4^{th} neutrino state

Neutrino and antineutrino generators

- Neutrino generators such as ^{51}Cr and ^{37}Ar have been used in the past
- Monoenergetic
- Require measurement of vertex position only for L/E

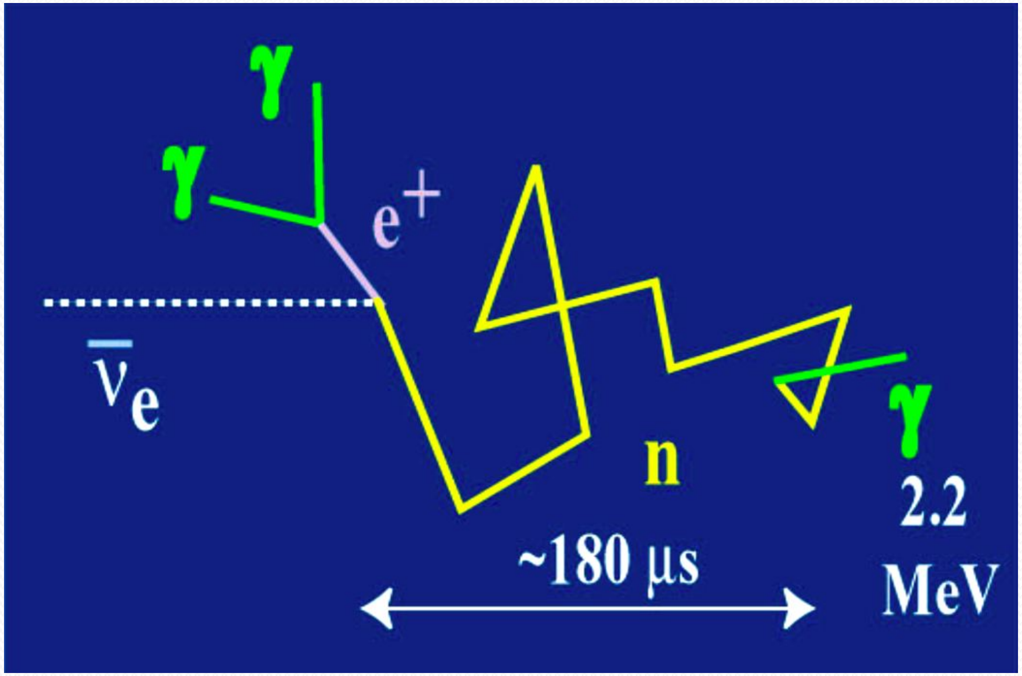
- Detection in LS via elastic scattering off electrons
  → must be very strong (5-10 MCi) to overcome solar neutrino background

- Antineutrino generators are detected in LS detected via inverse beta decay (IBD)
- Antineutrino energy > 1.8 MeV (IBD threshold)
- Lifetime > 1 month to allow time for production and transport
- Requires nuclei with high Q_β and long lifetime
- No single nucleus satisfies this condition

- *Pairs of beta decay nuclei needed: the first one with low Q_β and long lifetime followed by the second one with high Q_β and short lifetime*

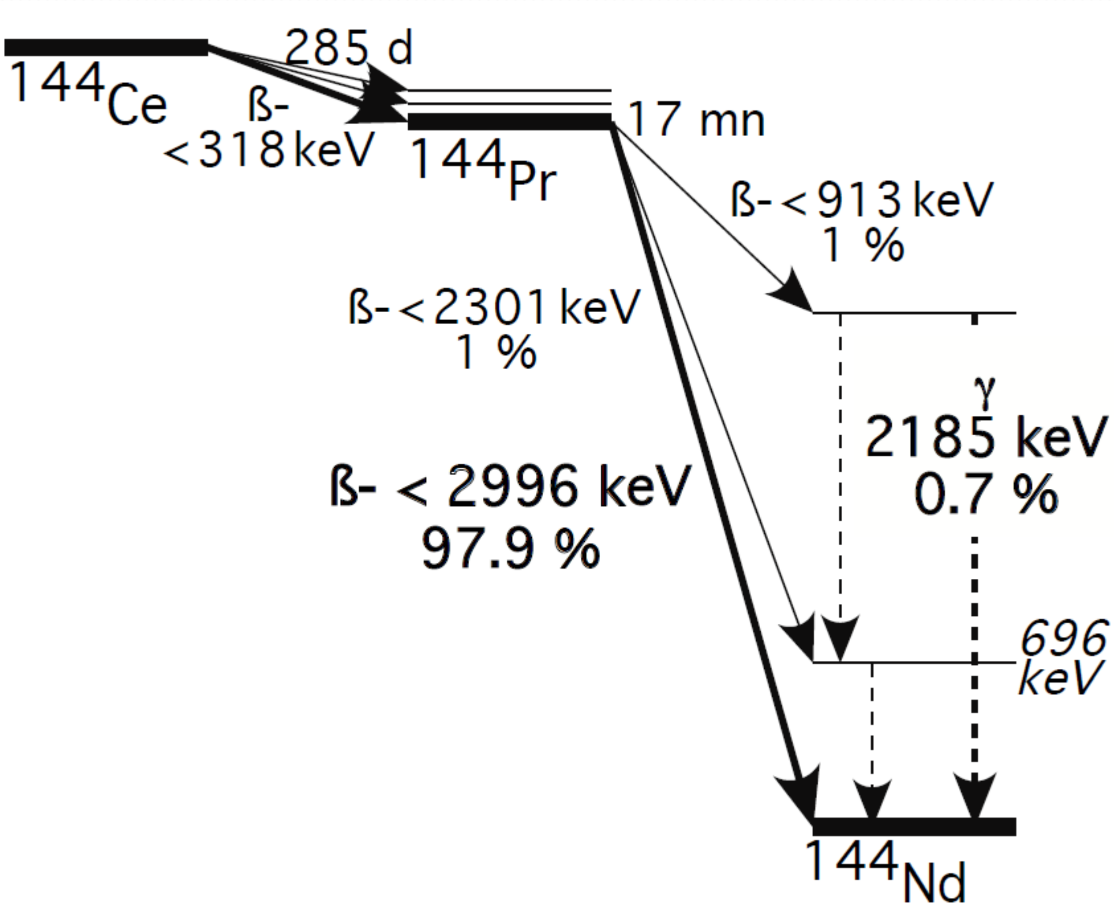
Inverse Beta Decay and Implications

$$\bar{\nu}_e + p^+ \longrightarrow n + e^+$$



- Dual, correlated signature in space and time
- Strong background suppression
- It is OK to use weaker source compared to neutrino ES source.
- 75 kCi source is sufficient for deployment in KamLAND

^{144}Ce – ^{133}Pr antineutrino generator



- Nuclei are in equilibrium
- Decay rate completely driven by ^{144}Ce
- Antineutrino emitted in ^{144}Ce decay below IBD threshold 1.8 MeV
- Antineutrinos above 1.8 MeV emitted in ^{144}Pr undergo IBD
- 75 kCi source is planned
- Main intrinsic background comes from 2.185 keV gamma with 0.7% branching ratio→ similar energy as 2.2 MeV deexcitation gamma from neutron capture on hydrogen

^{144}Ce source production I

- Natural cerium is mostly ^{140}Ce (88.45%)
- It is a soft, silvery, ductile metal that forms CeO_2 in presence of oxygen

- ^{144}Ce is a fission product, with 5.2% fission yield from ^{235}U
- It has the longest lifetime of all cerium isotopes (half-life 285 days)
- Its long half-life allows time for production from irradiated fuel, transport to reprocessing facility and year long deployment in the LS detector

- *Fresher irradiated fuel has a higher ^{144}Ce fraction, allowing a more compact packaging of the source, which is important for the oscillation measurement*

^{144}Ce source production II

- ^{144}Ce source will be produced at Mayak reprocessing facility in Russia
- They will produce (85^{+15}_{-10})kCi source based on the beta activity measurement with 8% uncertainty.
- Excellent chance to get a source above 75 kCi activity at KamLAND

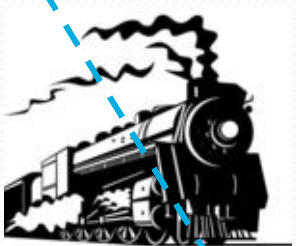
- Usage of standard Mayak container with double capsule walls (3 mm and 4 mm thick steel wit 0.5 mm gap) foreseen

- Extra space (if available) will be filled with additional CeO_2 up to 100 kCi activity free of charge!
- This will depend on the fuel age; typical SNF 3-5 years old; possibility to use fresher fuel, just 1.7- 2 year after irradiation!
- ^{144}Ce fraction between ($0.6^{+0.1}_{-0.15}$)% at 3 years after irradiation

^{144}Ce Production at PA Mayak: 2014

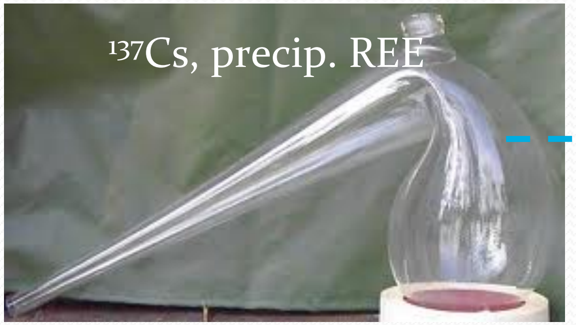
75 kCi (2.77 PBq), 10 kg of CeO_2 (3y, ρ= 4.5 g/cm^3), 600 W

VVR-440, storage



TUK-6

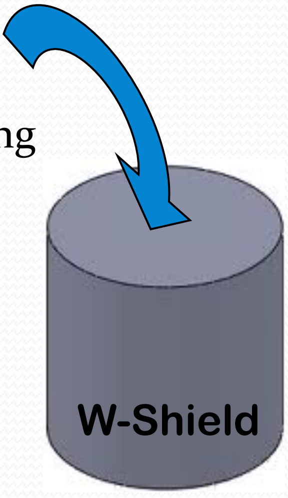
PUREX – Plutonium Uranium Extraction



Rare earth elements precipitation

CeO_2 calcination

Pressing



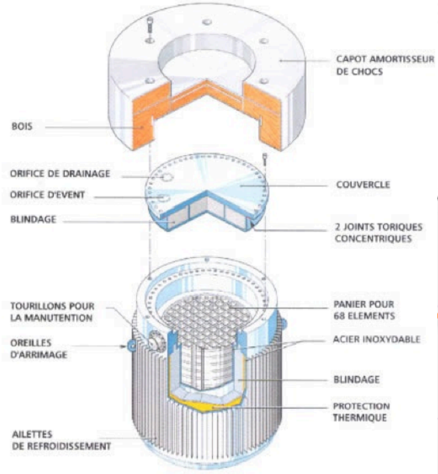
High Z-shielding

- Tungsten shielding Desnimet-185 or similar will be used (ρ = 18.5 g/cm^3)
- Shielding has two-fold purpose:
  - Biological protection during transportation and handling
  - Suppression of the 2.186 MeV gamma during deployment: 525 Ci activity from 75kCi ^{144}Ce
- Biological protection is estimated in terms of equivalent dose received by a person at 1 m distance from the surface of the shield/container
- 16 cm thick tungsten shield around 75 kCi source is sufficient for biological and deployment protection → 3 ton weight
- Several transportation options under consideration

Transportation options

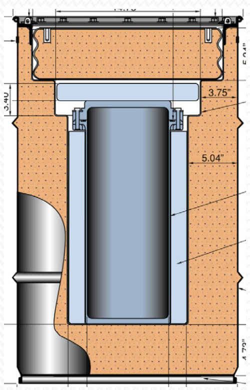
Boat

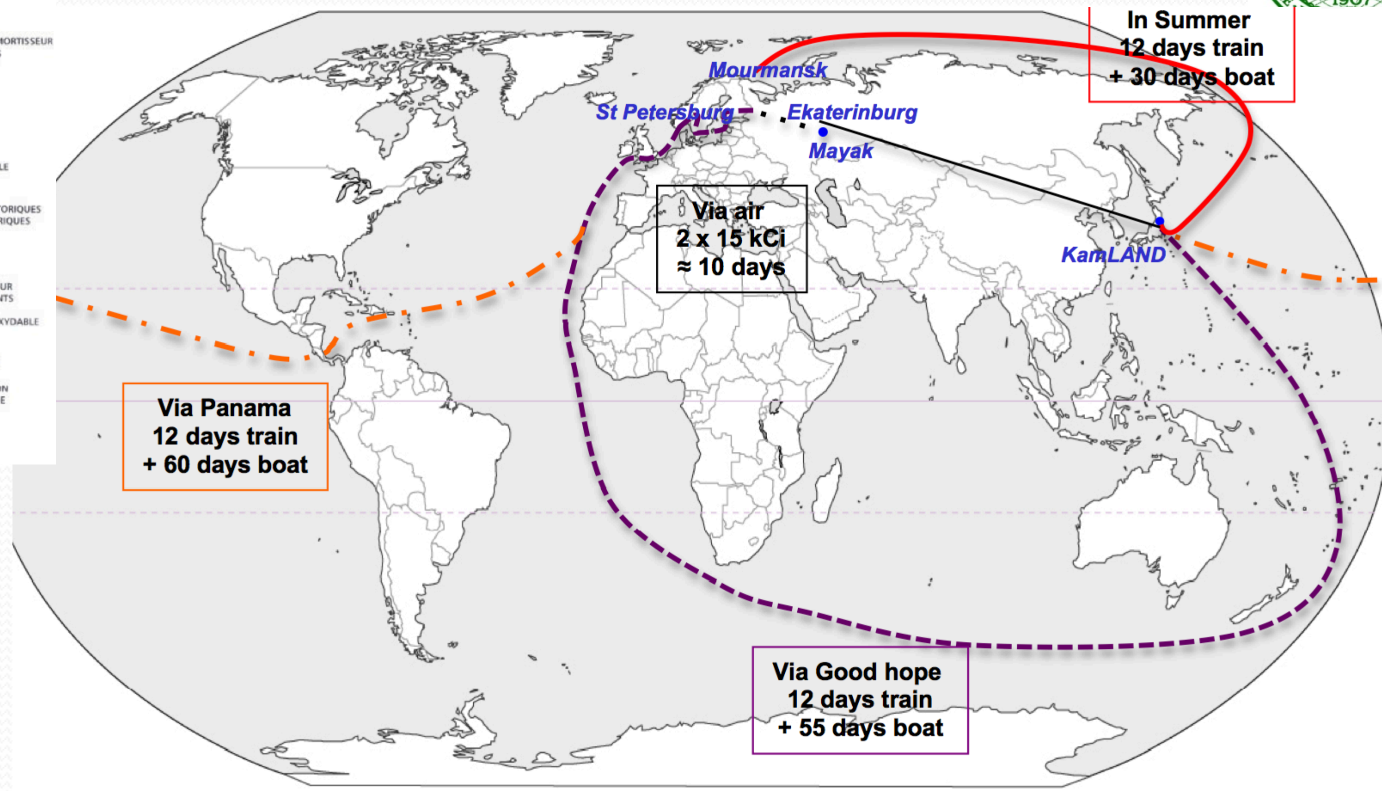
- 23 tons !



500 lb

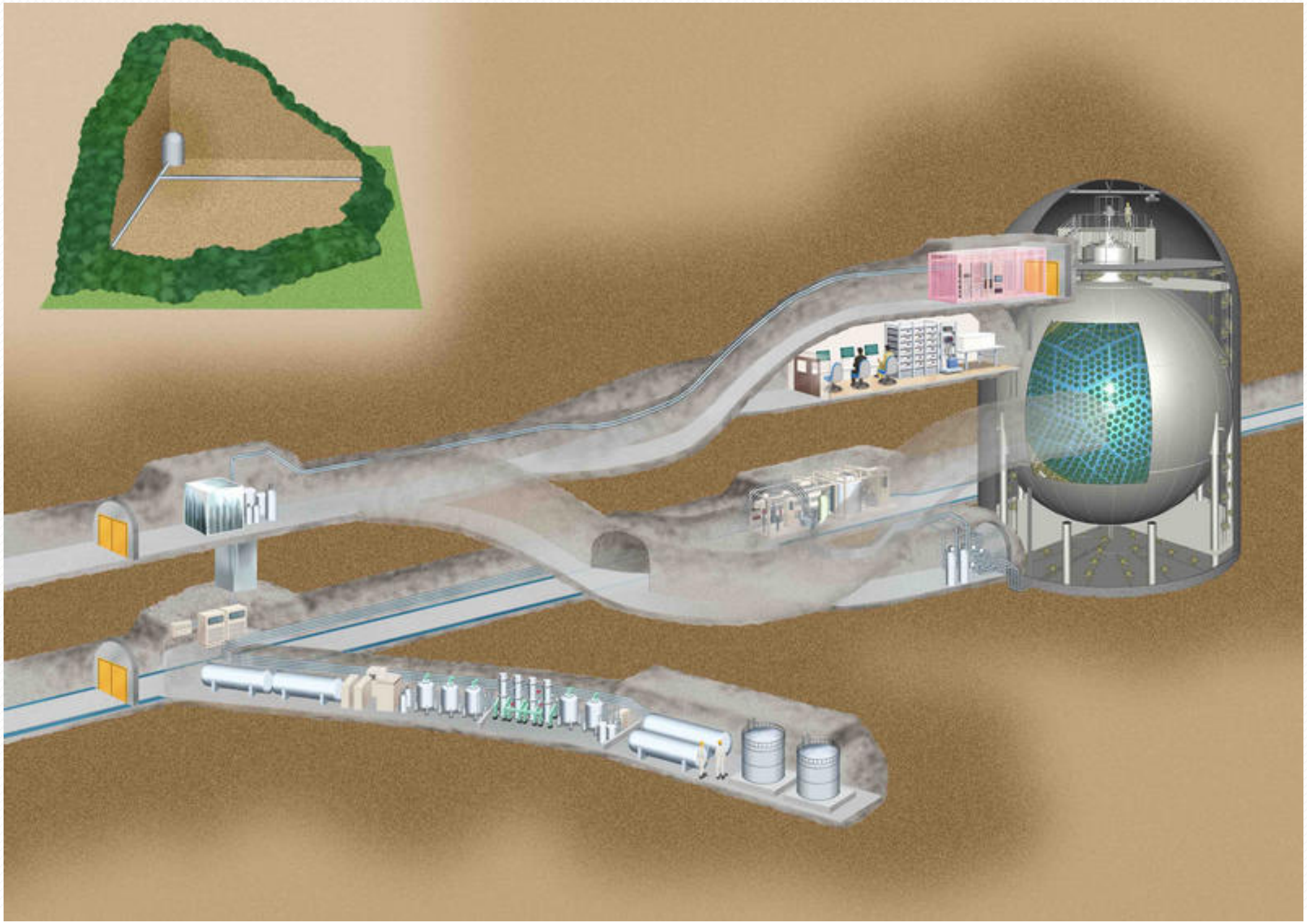
Air?





- By boat: slow and limited number of harbours can receive the source
- By air, 16.2 kCi limit in a single container imposed by IAEA
- No container so far has certificates for both Russia and Japan
- Investigating possibility for a special arrangement for transportation

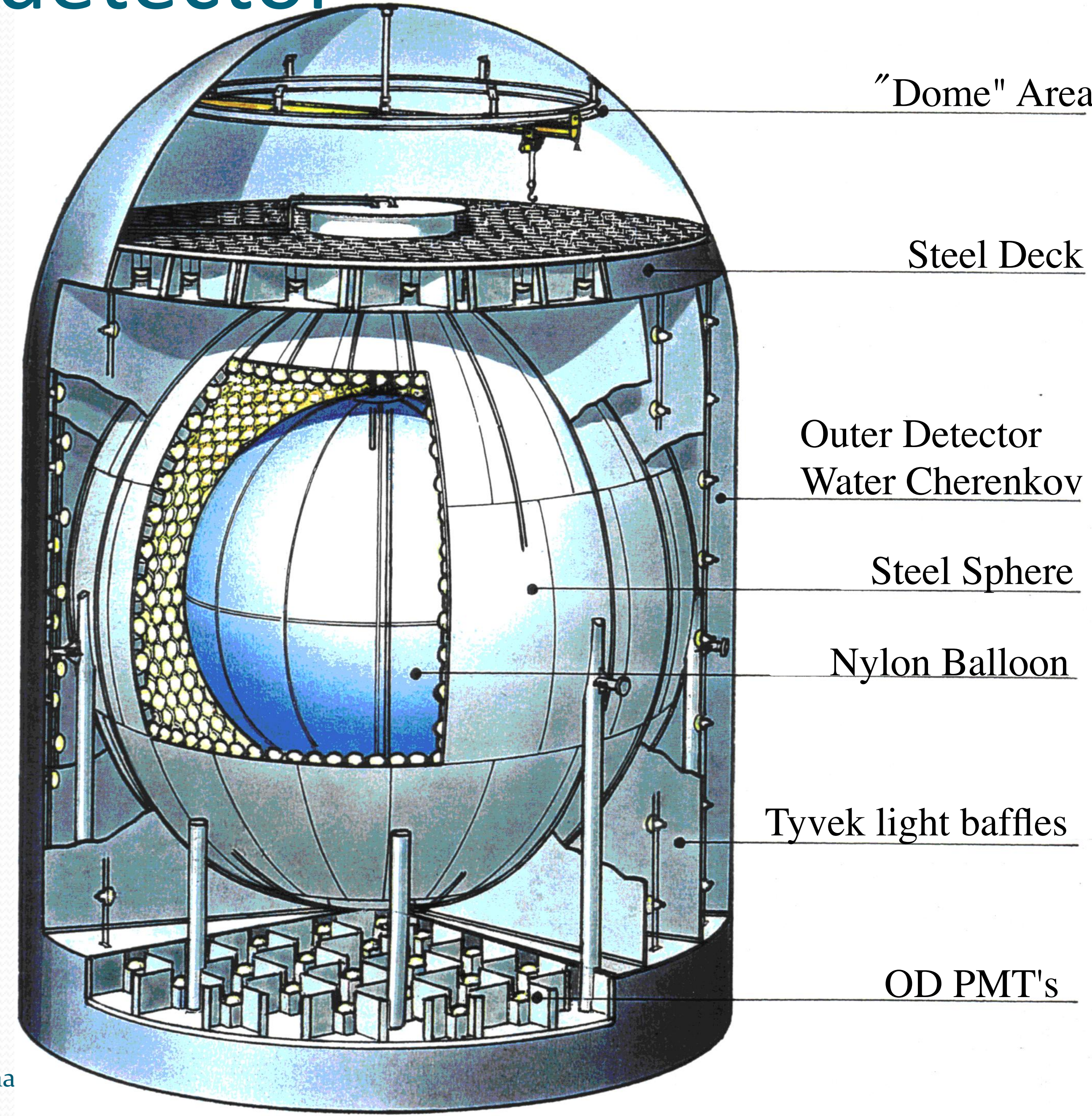
KamLAND location



- 2700 mwe overburden
- Excellent place for the source experiment

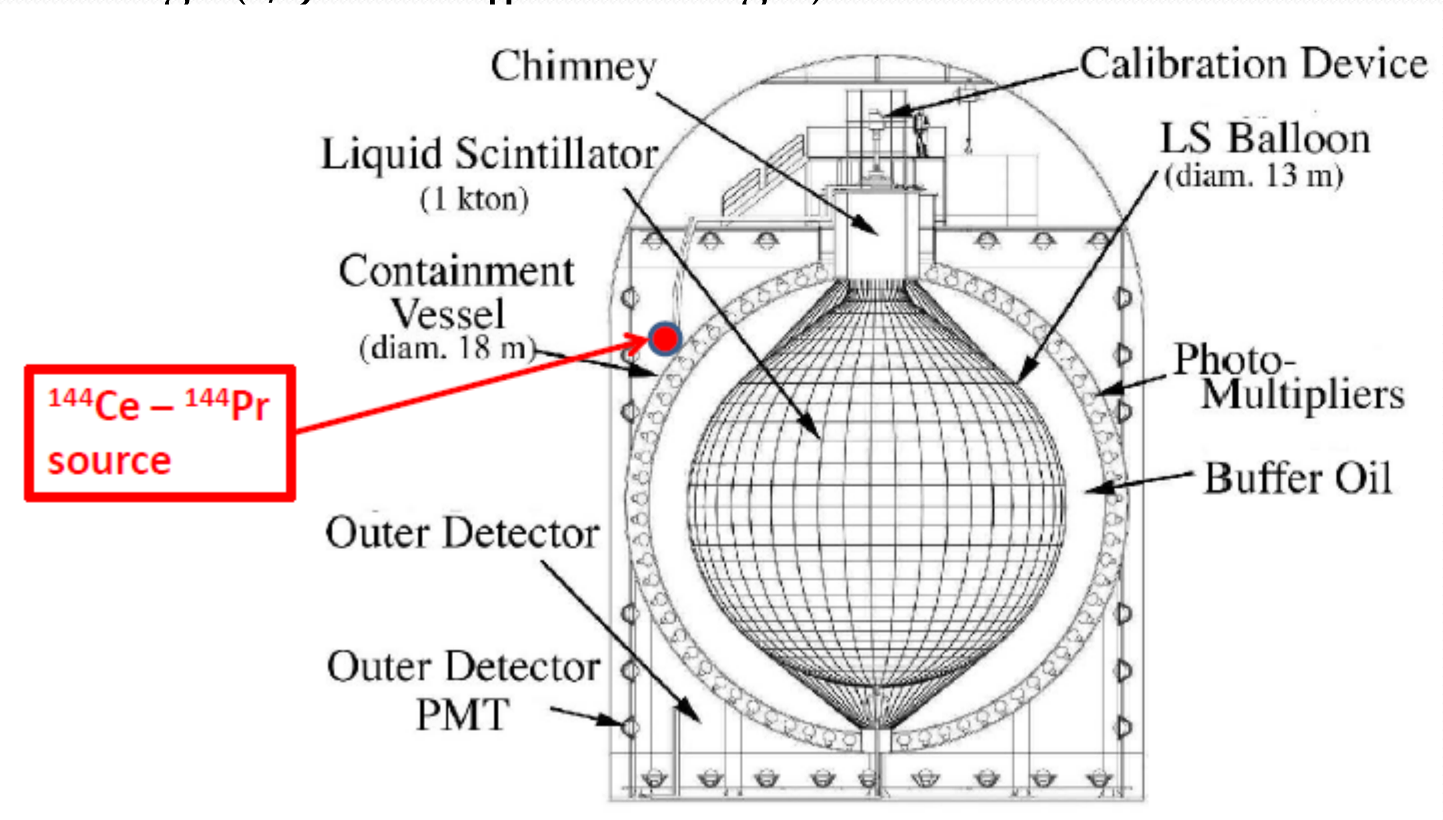
KamLAND detector

- 1 kton liquid scintillator
  - 80% paraffin oil
  - 20% pseudocumene
  - 1.5 g/L PPO
- Paraffin outside the nylon balloon
  - radon barrier
- 1879 PMT's
  - 1325 17" - fast
  - 544 20" - efficient
  - 34% coverage
- 225 Veto PMT's
  - Water Čherenkov

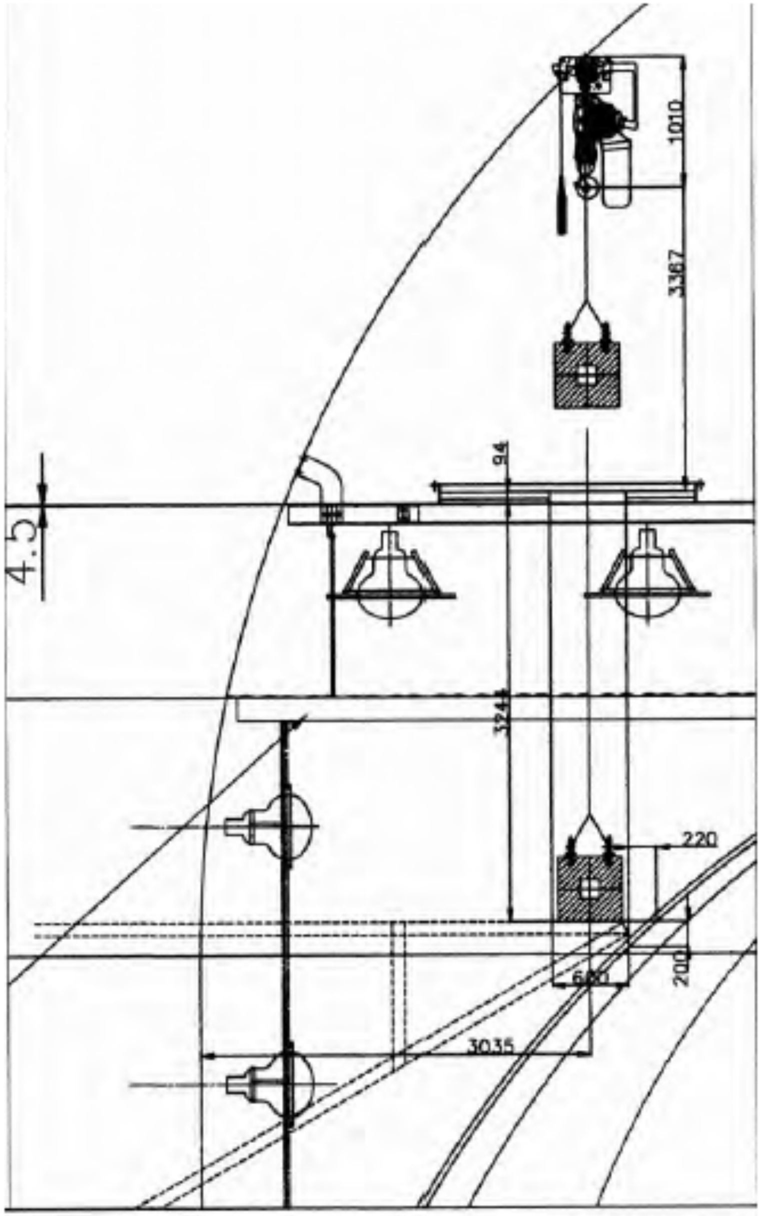


Antineutrino generator in KL OD

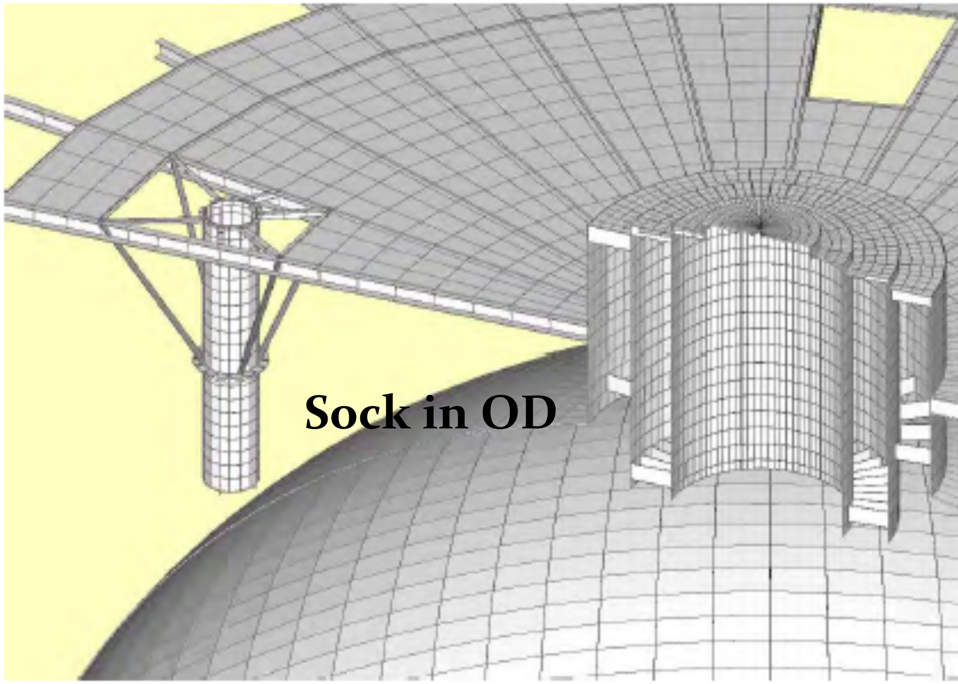
- Advantages: safe, relatively simple to deploy through the access hatch of the OD, baseline 3.0 – 16 m, excellent shielding by 2.5 m thick layer of buffer oil; easier cooling; deployed in water as opposed to scintillator
- •Disadvantages: lot of neutrinos lost due to partial solid angle coverage (1/5 of the 4pi solid angle)



Containment structure in OD



- Preliminary considerations conducted:

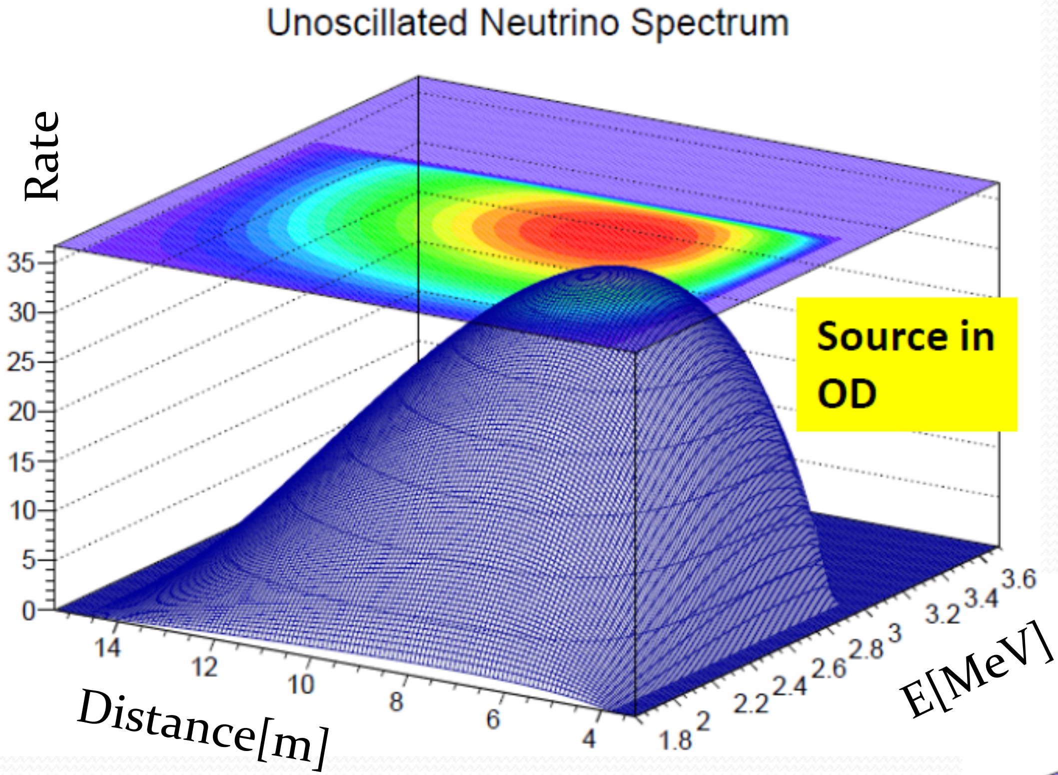


Expected rate

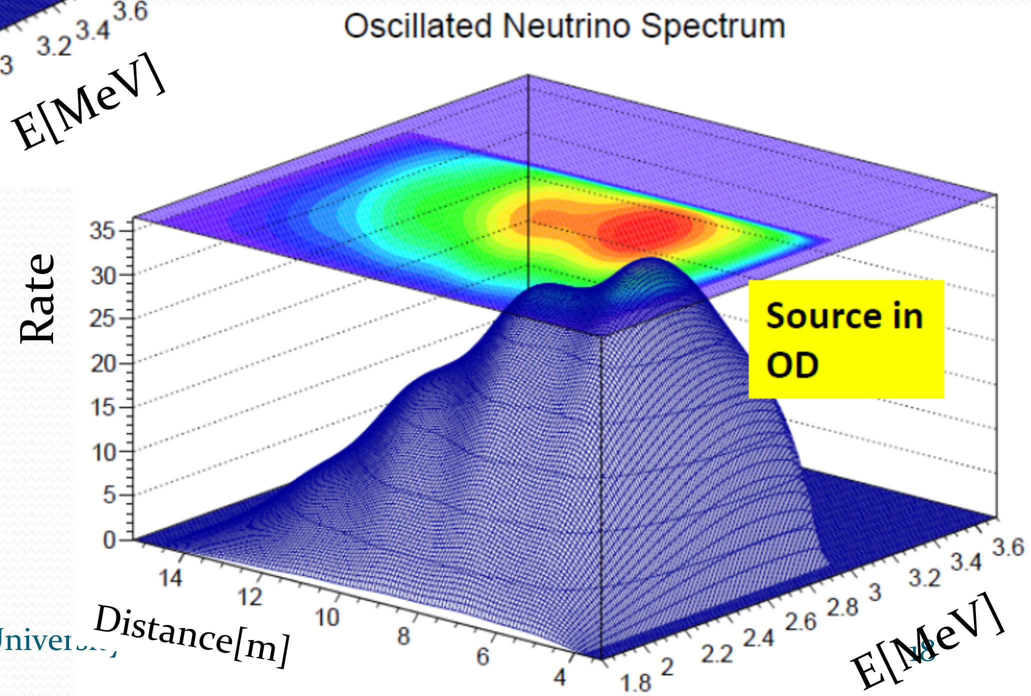
- 75 kCi source for 18 months and $t_{1/2}$ = 285 days for ^{144}Ce
- Vertex resolution ~15 cm
- Energy resolution ~5%
- Fiducial volume cut at R = 6 m
- Assume that the source can be placed right next to the buffer vessel, so distance of the source from center of KL 9.5 m

- ~20,000 interactions in no oscillation scenario
- Using $$P = 1 - sin^2(2\theta_{new}) \cdot sin^2(\frac{1.27\Delta m^2_{new} L[m]}{E[MeV]})$$
- We get ~19,000 interactions for $$sin^2 2\theta_{new} = 0.1$$ $$\Delta m^2_{new} = 2 \text{ eV}$$
- Compared to the same source in the center we get around 1/5 of rate in unoscillated case.

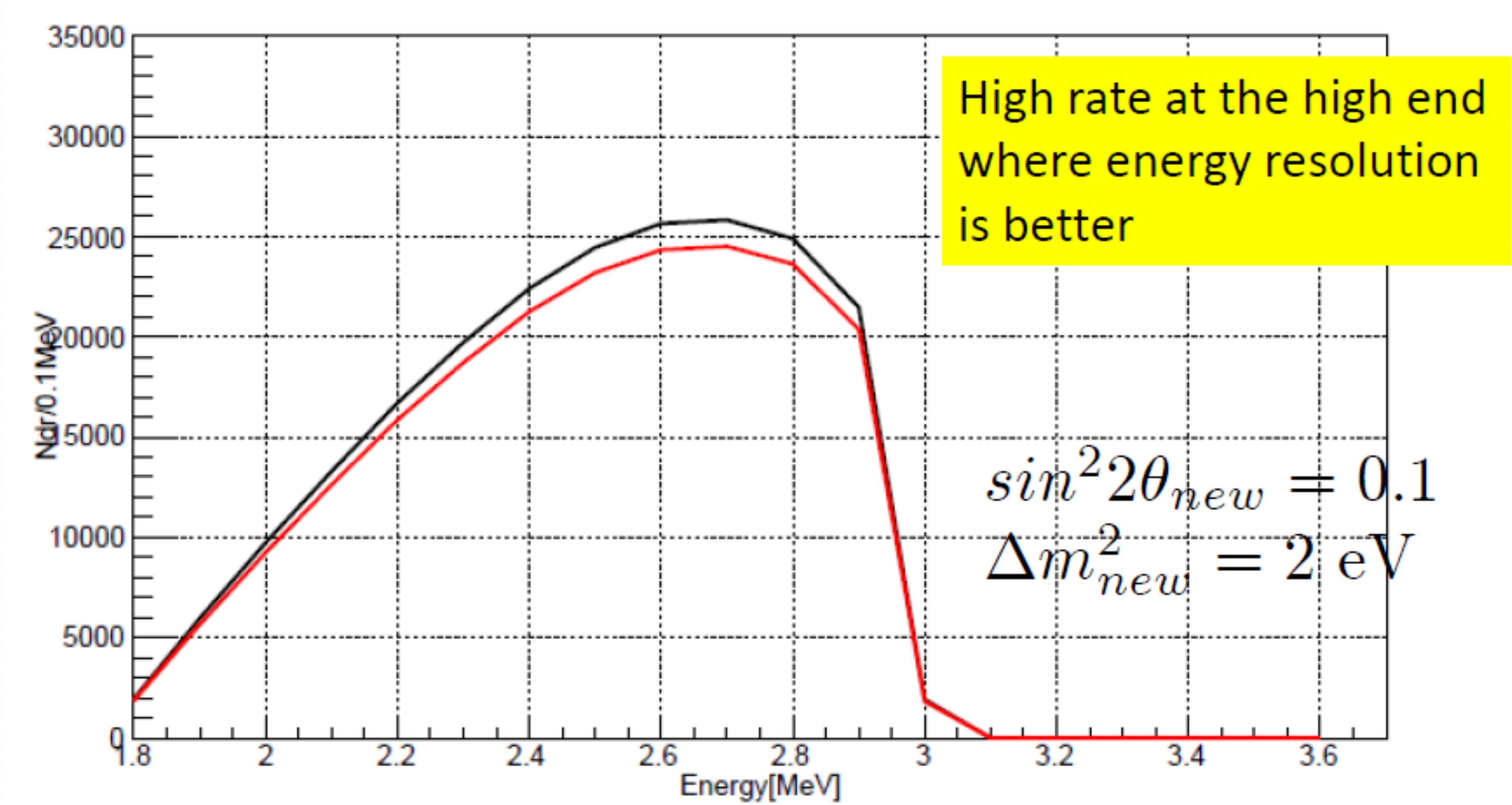
Oscillated vs Unoscillated Spectrum



$$sin^2 2\theta_{new} = 0.1$$
$$\Delta m^2_{new} = 2 \text{ eV}$$

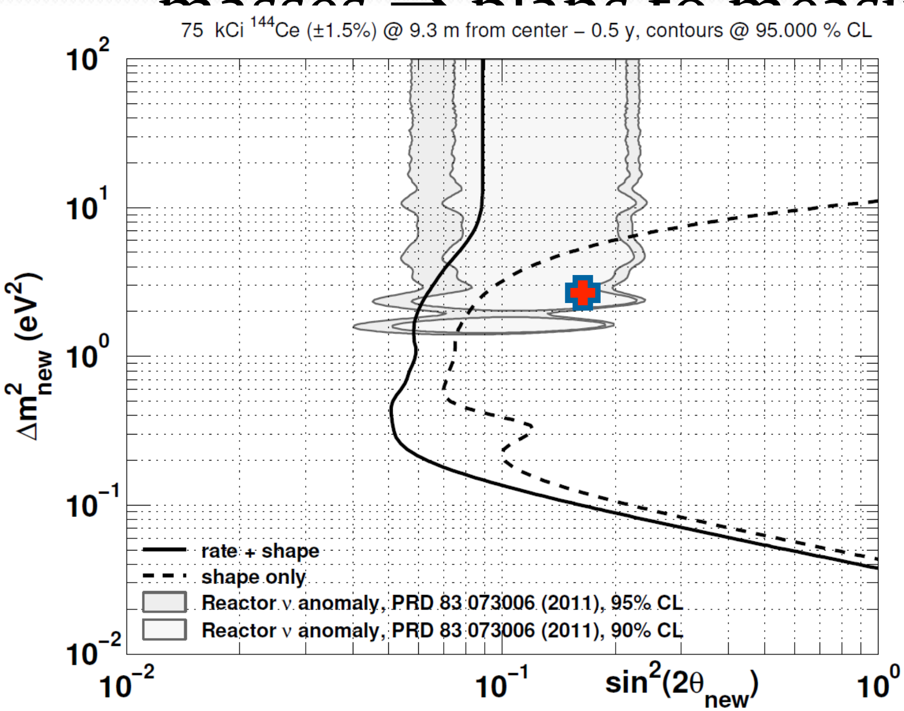


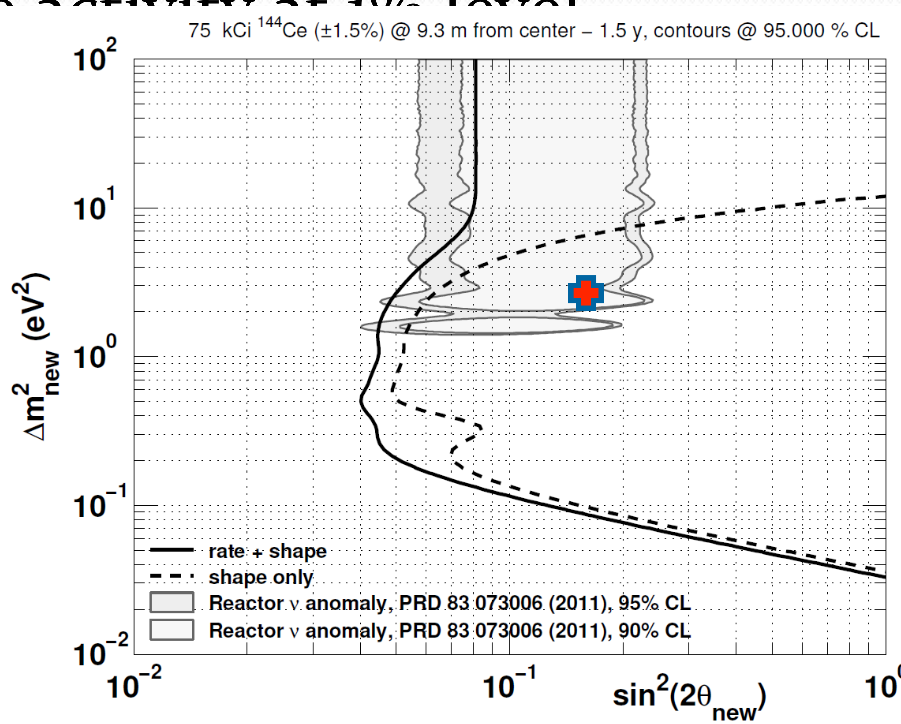
Cumulative Rate vs. Energy



Sensitivity to oscillation

- The best fit RAA solution can be probed after 0.5 years
- Strong bounds come from rate constraints at higher masses → plans to measure activity at 1% level



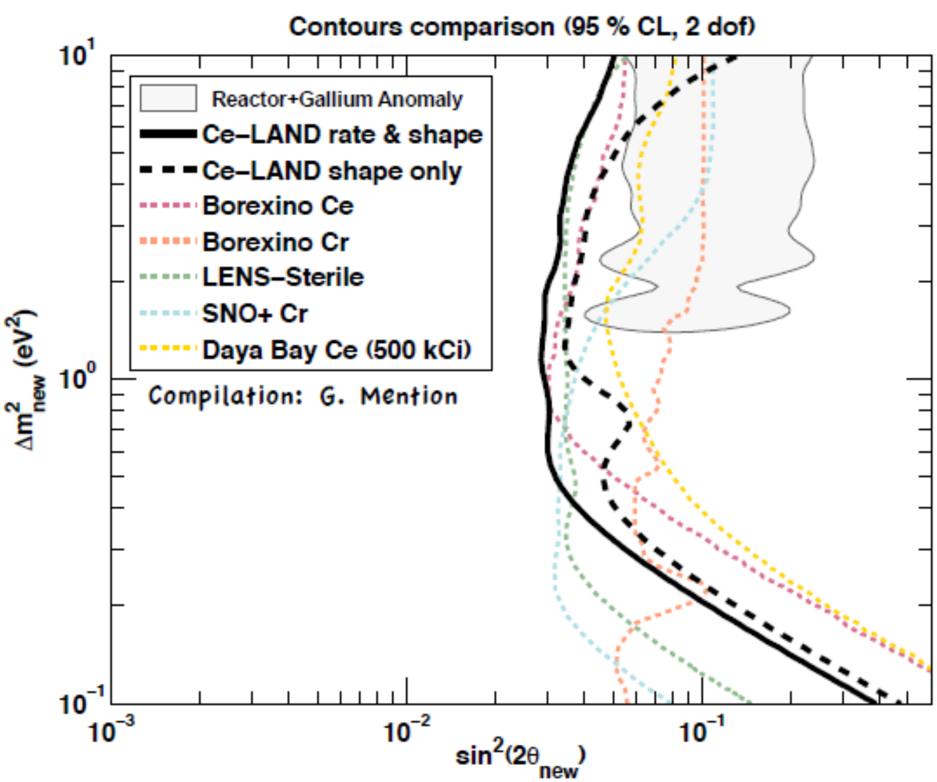


Courtesy of T. Lasserre

Summary and future steps

- Strong antineutrino sources have excellent potential to test reactor antineutrino anomaly and search for the 4th neutrino
- First time ever test of the 1-10 m baseline
- Production and transport of the source represents significant technical challenge
- With just 0.5 years of data taking interesting limits can be placed on RAA

- The most direct and simplest approach for detecting sterile neutrinos in this parameter space.
- Source delivery in 2014 and deployment in KL in 2015.



Courtesy of G. Mention